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Testing

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Testing is conducted to verify that the connectors will properly perform over time (reliability) per the application requirements. Testing by the manufacturer usually involves performance testing per the datasheet requirements. However, the customer may have applications that require performance under unique operational and environmental conditions. In general, electrical tests for connectors include dielectric withstanding voltage, low-signal-level contact resistance, insulation resistance, contact resistance, and standing wave ratio. Environmental tests include humidity, temperature, and contaminating conditions, as well as mechanical stress environments including vibration, mechanical shock, and durability cycling exposures. To assure the performance and reliability of connectors, manufacturers usually do qualification testing, which includes a series of tests that specify connectors to certain requirements. Table 10.1 shows an example of qualification testing.

10.1 Dielectric Withstanding Voltage Testing

The purpose of the dielectric withstanding voltage test is to verify that the connector can operate at its rated voltage and will be able to withstand momentary over-potentials due to switching and/or surges. Also known as a high-potential, over-potential, or dielectric-strength test, this test differs from a dielectric-breakdown test. In cases where the applied voltage causes a sudden breakdown of the insulation material that provides a flow of current, the insulation is determined to be dielectric-insufficient. While the dielectric withstanding voltage test is widely used, the real objective of the test is often misunderstood, which may lead to incomplete testing or misleading test results. Simply stated, the test voltage breaks down the insulating properties of the material [1, 2]. The dielectric breakdown of an insulating material is a complex physical phenomenon but it may be generally characterized as a sudden change in the resistance of the insulation under test due to the applied voltage. The mechanism of dielectric breakdown begins with the application of a strong electric field to the insulating material by a high voltage, which in this case would equate to the dielectric withstanding voltage set in the test. Different materials require different levels of electric field for dielectric breakdown

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to occur. Metals and other conductors have free electrons without the application of any electric field, but insulating materials typically require a high electric field to allow electrical current to flow. When the electric field is sufficient, it energizes the insulator's electrons until they gain enough energy to cross the bandgap and move into the conduction band, dramatically increasing the conductivity of the material. This transformation is called "dielectric breakdown," and the electric field necessary to start the breakdown is called the "dielectric strength" or "breakdown strength." Thus, dielectric breakdown is a dramatic and sudden increase in the conductivity of a material due to an applied voltage.

The specimens required for the dielectric withstanding voltage test are usually a plug, receptacle, or mated combination as specified in the individual connector specification. The equipment is a voltage source adjustable to within a certain tolerance of the required test voltage (DC or root-mean-square [RMS]) and capable of delivering a minimum current of approximately 1 mA. The applied voltage can be either alternating current (AC) or direct current (DC). The voltage should be applied across the two closely spaced contacts as well as between the connector shell and the contacts closest to the shell. In the case of coaxial connectors, the test voltage is applied between the inner and outer conductors. The voltage is usually ramped up uniformly from zero to the rated value. The test can be performed at various pressures depending on the application for which the connector is going to be used. For example, in undersea applications, the pressure on the connectors will be high [3].

All insulation will break down at some specific voltage. Above this critical voltage, the current flow will increase catastrophically. Per methods such as the MIL-STD-1344A, Method 3001.1, the dielectric withstanding voltage is 75% of the minimum breakdown voltage; it is suggested that the operating rated voltage should be one-third of the dielectric withstanding voltage. During measurement, usually an alternating potential is applied between the adjacent contacts, the voltage is increased from zero to the specified value as uniformly as possible at a specified rate and, the test voltage is maintained at the specified value for one minute to see whether the material breaks down. This method is often called the "step-by-step test." In another method, the short-term dielectric withstanding voltage is obtained by steadily increasing the test voltage from zero to breakdown. The magnitude of the test voltage is expressed as its RMS value. Since the barometric pressure greatly affects the withstanding voltage characteristics of the connector, the dielectric withstanding voltage is usually specified for sea-level applications. The breakdown voltage is influenced by the dielectric strength of the insulator, duration of the applied voltage, thickness of the sample, temperature, surrounding medium, and frequency of the applied voltage. The dielectric strength is a property of an insulator, expressed as the maximum voltage gradient that causes insulator breakdown. The dielectric strength of insulators can be obtained from many books.

10.2 Insulation Resistance Testing

The purpose of the insulation resistance test is to assess the resistance offered by various insulation materials and seals of a connector or coaxial contacts to the DC voltage that tends to produce a leakage current through or on the surface of these contacts [3].

The test is designed to assess the quality of insulation material used in the connector by measuring the amounts of leakage current between the conductors of a connector. Electrical insulation begins to age as soon as it is installed, and this deterioration can affect the performance of the connector. Insulation resistance testing is also used as quality control during production of the connector and preventive maintenance tasks and as a troubleshooting tool.

The insulation resistance is measured using a mega-ohm bridge or a mega-ohm meter. Voltage is applied to the conductors of the connector, – the voltage is always lower than the voltage required for performing the dielectric testing. The current flowing through the conductors of the connector is then measured. Typical values of insulation resistance, as measured by a high-resistance meter, such as the Keysight 4339B DC High-Resistance or the B2980A Series Femto/Picoammeter and Electrometer/High Resistance Meter[1] for the insulator of a connector, range from mega-ohms to tera-ohms. Temperature and humidity can affect the value of the insulation resistance and secondarily the value of the leakage current. These factors may significantly affect the measurement result. Temperature causes the insulation resistance value to vary quasi-exponentially. If the end-use condition of the connector is going to include application conditions with elevated temperature or humidity, then those environmental requirements need to be incorporated in the test protocol.[2]

The insulation resistance test is performed on a sample of the connector receptacle or mated connector as specified in the individual connector specification. In some cases, the connector or receptacle is cleaned prior to connections or the test. The cleaning process ensures that the contacts are free from contaminants that can influence the insulation resistance; contaminants can include moisture, excess dust, oil, or other surface contaminants. If the receptacle or the connector has been subjected to environmental conditions, the tests should be performed rapidly to prevent the equalization of the samples with the ambient conditions in the laboratory. Typically, a period of a half-hour to three hours after removal from the chamber is recommended.[3] The resistance is typically measured either between the individual pairs of immediately adjacent contacts pins and the shell or between the hardware to which the connector is attached and the closest contact. Once the connections are made, a test potential, typically 500 VDC, is applied for a two-minute period. The insulation resistance is measured immediately after the electrification period.

Some standards for measuring the dielectric breakdown constant and insulation resistance are listed here for reference:

American Society for Testing and Materials (ASTM)-D-149: Standard test method for dielectric breakdown voltage and dielectric strength of solid electrical insulating materials at commercial power frequencies

Electronic Industries Association (EIA)-364-TP20: Withstanding voltage test procedure for electrical connectors

MIL-STD-1344, Method 3001: Dielectric withstanding voltage test method for electrical connectors

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[1] B2980A Series Femto/Picoammeter and Electrometer/High Resistance Meter datasheet.

[2] TP-29C. *Contact Retention Test Procedures for Electrical Connectors*, EIA/ECA-364-29C.

[3] IPC Test Document. *IPC-TM-650 3.6, Insulation Resistance, Connectors.*

Table 10.1 Qualification testing sequence for slot connectors required by Intel.

	Test Group									
Test	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Visual inspection	1, 11	1, 6	1, 6	1, 9	1, 8	1, 5	1, 4	1	1	1
Dimensional verification	2	2	2	2	2	2	2	2	2	2
Contact resistance	4, 6, 9	3, 5	3, 5		3, 5, 7					
Insulation resistance				3, 7						
Dielectric withstand voltage				4, 8						
Vibration	8									
Shock	7									
Durability	5									
Mating force	3									
Un-mating force	10									
Thermal shock										
Temp. cycling				5	4					
Temp. life		4		6	6					
Mixed flowing gas			4							
Resistance to solder heat							3			
Porosity								3		
Plating thickness								4		
Solvent resistance									4	
Normal force								5		
Solderability								6		
Contact retention									3	
Max. force on connector						3				
Contact back out wipe						4				
Current rating										
Substrate visual inspection	12									3
Sample size	16	8	4	8	8	4	4	4	4	4

ASTM-D-257: Standard test method for DC resistance or conductance of insulating materials
EIA-364-TP20: Insulation resistance test procedure for electrical connectors
MIL-STD-1344, Method 3003: Insulation resistance test method for electrical connectors

Table 10.1 shows an example of qualification testing.

10.3 Contact Resistance Testing

The contact resistance test is used to identify problems with loose connections, eroded contact surfaces, and contaminated or corroded contacts. It is also used to measure the contact resistance between the mated connectors contact attached to the wire. The test is performed by measuring the milli-voltage drop across the connector when it is carrying a rated current. The resistance is calculated from the voltage and current data [3].

A connector introduces extra contact interfaces between electronic devices. To maintain a consistent and reliable contact interface, a contact force should be applied. The applied contact normal force depends on the contact resistance that can be achieved. When two contacts are mated, the work of an external force, such as the insertion force, causes contact deflection. Consequently, a contact normal force is exerted on the contacts, and a contact interface is created. This interface is usually not as tight as it seems to be, from a microscopic view. The surface roughness, surface insulation film, contamination, and dust in the contact interface prevent real metallic contact. The effective contact area is usually a fraction of the total contact area; this fraction is determined by the contact manufacturing process, contact finish, and contact cleanness. The surface roughness is usually described by “asperities.” Asperities are the protruding spots on a surface; during mating, only asperities actually come into contact. Due to their small size (the radii are measurable in micrometers), the asperities deform plastically even at low applied loads. With increased loads, the asperities deform further, the contact area is enlarged constantly, and more asperities touch each other. The number of asperities mainly depends on the surface roughness, material hardness, and magnitude of contact normal force. The limited contact area results in a contact resistance called “restriction resistance”: the current flow is restricted to flowing through the asperities. Figure 10.1 shows a schematic of the contact interface, asperities, and restricted current flow.

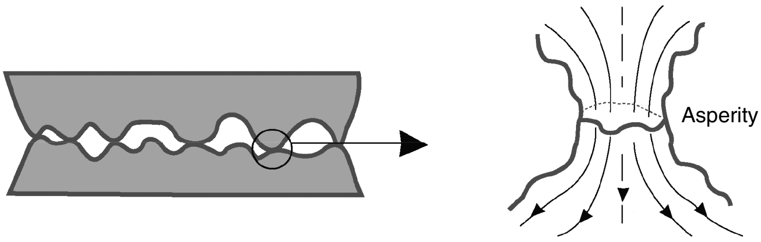
The constriction resistance as a function of the number, combined area, and distribution of multiple asperities is described by the following equation:

$$R_C = \frac{\rho}{na} + \frac{\rho}{D} \tag{10.1}$$

where ρ is the resistivity of the contact material (assuming the same materials), n is the number of asperities, a is the diameter of the asperity, and D is the diameter of the area over which the contacts are distributed.

As mentioned, the area of the asperities is determined by the applied load; thus, the constriction resistance can be expressed in terms of the contact normal force [4]:

$$R_C = k\rho \left(\frac{H}{F_n} \right)^{1/2} \tag{10.2}$$



(a) Contact interface

(b) Constricted current flow

Figure 10.1 Schematic of (a) contact interface and (b) asperity.

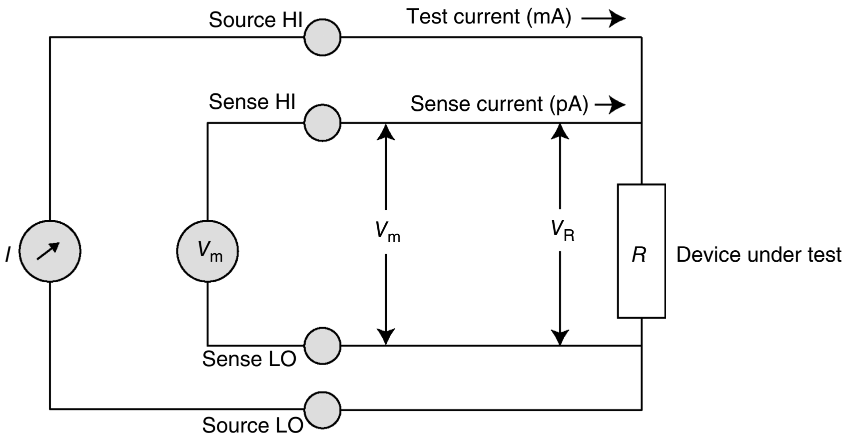


Figure 10.2 Schematic of four-wire measurements.

where k is a coefficient including the effects of surface roughness, contact geometry, and elastic/plastic deformation, which can be determined experimentally, H is the hardness of contact material, and F_n is the contact normal force.

In Eqs. (10.1) and (10.2), a pure metallic surface is assumed; however, in most applications, the conditions of the contact surfaces are not perfect; surface films may grow initially or develop gradually during connector application. Surface films may be displaced or disrupted completely or partially or remain intact, depending on the applied contact force, and applied bias, as well as film composition, structure, and thickness. Applied bias may cause the electrical breakdown of surface films. Applying a normal force may mechanically disrupt the oxide layers and expose the metallic contacts. The film composition, structure, and thickness depend on the contact finish and application environment. In principle, the overall contact resistance can be regarded as a combination of constriction resistance, due to asperity contact, and film resistance, due to the oxide or corrosion film accumulated on the contact surfaces.

The four-wire method is commonly used to measure contact resistance. A sourcing current is applied to flow through the contact interface, and the voltage across the interface is measured (Figure 10.2). The measurement can be made using a micro-ohmmeter, or a separate current source and voltmeter. With this configuration, the test current (I) is forced through the contact resistance through one set of test leads, while the voltage across the device under test is measured through a second set of leads called "sense" leads (the voltage is usually negligible, typically in the order of pA or less). Therefore, the voltage measured by the meter is essentially the same as the voltage across the contact resistance. The sourcing current and voltage must be carefully controlled to avoid the breakdown of interface insulation films (shown in Table 10.2).

The test condition is often called a "dry-circuit" condition; that is, with an open-circuit voltage less than 20 mV (the breakdown voltages of metal surface films are usually in the range of 30–100 mV) and a short-circuit current less than 100 mA, devices are tested in a manner that will not puncture any oxide film that may have built up on the contacts and changed other physical properties.

Table 10.2 Breakdown and melting voltage of surface insulation films.

Contact Material	Softening Voltage (mV)	Melting Voltage (mV)
Au	80	430
Ni	220	650
Cu	120	430
Ag	90	370
Sn	70	130

Some standards for testing contact resistance are listed here for reference:

EIA 364-TP04: Normal force test procedure for electrical connectors

ASTM B-539: Test methods for measuring contact resistance of electrical connections (static contacts)

EIA 364-TP06: Contact resistance test procedure for electrical connectors

MIL-STD 1344, Method 3004: Contact resistance test method for electrical connectors

International Electrotechnical Commission (IEC) 60512-2: Electromechanical components for electronic components: Basic testing procedures and measuring methods – Part 2: General examination, electrical continuity and contact resistance tests, insulation tests and voltage stress tests

The test involves a four-terminal resistance measuring technique wherein a measured and controlled test current is introduced into the sample using two "terminals" or connecting points, and two other points are selected on the sample across which a voltage drop is measured. This voltage drop, divided by the test current, is the effective overall resistance of the sample included between the voltage probes. The voltage-measuring points are chosen so as to measure as closely as possible the voltage drop due only to the contact resistance of the sample and to eliminate from the measurement as much as possible the resistance of the metal pieces comprising the contact and the resistance of the wires and connections used to introduce the test current into the sample. Usually, the test is run with two levels of test current. The choice of which level to use is governed by the application and requirements of the electrical connection being tested.

10.4 Current Rating Testing

Current rating, also called current carrying capacity, specifies the maximum current that a conductor can carry safely. Due to current flow, Joule heat is generated in the conductor, and the local temperature increases. The local temperature rise, compared with the ambient temperature, depends on the balance between Joule heat and heat dissipation to the neighboring regions. If the flowing current is too large, excessive heat will be generated and accumulated, and the local temperature will rise so high that it may surpass the maximum operating temperature of the insulators that separate the connector contacts. The maximum operating temperature of the connector housing determines the maximum current flow through a connector contact.

Although the current rating can be specified in terms of the transient current rating or overload current rating, the continuous current rating has generally been adopted by the connector industry. This current rating is based on the local temperature rise above the ambient, as induced by the current flow. It is commonly taken as the current that produces a 30 °C temperature rise, though other criteria can be used, such as a 10 °C T-rise. The criterion can be applied to both AC and DC current.

The current rating depends on the contact size, contact pitch, contact type, and heat-sinking capability. A large contact size assures a high current rating. The current rating for a connector may be 10 times larger than the current rating for an integrated circuit (IC) socket. The contact pitch for the socket contacts also limits the applicable current rating. A high-conductivity contact may be adopted to compensate for the reduction of contact size and pitch. High conductivity connector contacts not only generate less heat but also dissipate heat more effectively. The current rating performance will be greatly improved if a heat sink is attached, as a heat sink greatly enlarges the area of heat dissipation.

Some standards for current rating are listed here for reference:

EIA 364-TP70A: Temperature rise versus current test procedure for electrical connectors and sockets

IEC 60512-3: Electromechanical components for electronic equipment; Basic testing procedures and measuring methods – Part 3: Current-carrying capacity tests

IEC 60512-10-4: Electromechanical components for electronic components: Basic testing procedures and measuring methods – Part 10: Impact tests, static load tests, endurance tests and overload tests, Section 4: Test 10d: Electrical overload

The test is usually run with an electrical overload current flowing through contacts for a limited period of time ranging between 100 ms and 20 seconds. The test procedure is based on measuring the increase of temperature during the specified period of time when the electrical overload is applied to the contacts. Temperature increase over time is measured for an electrical overload current, specified as an integer multiple of the rated current, and an overload current-over-time diagram is plotted. Practice shows that, for limited periods of time, contacts can conduct a multiple of the maximum permissible current without damage to the contact area. At least three mated connectors are wired with the maximum wire size for the contacts with the shortest possible wire lengths compatible with the contact arrangement. The overload current is applied for a period of time and switched off as soon as the temperature has reached the upper temperature limit defined in the specification. The samples are then allowed to recover to room temperature before the next cycle is carried out. The test is repeated with different overload currents to plot temperature–time curves.

10.5 Electromagnetic Interference and Electromagnetic Compatibility Testing

Electromagnetic interference (EMI) is the effect of an electromagnetic phenomenon degrading the performance of a device, equipment or system. Related to EMI, electromagnetic compatibility (EMC) is the ability of a device, equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to that environment. Products must not be susceptible, or, in other words, must be immune, to EMI, such as electrical fast transients (EFTs) and electrostatic discharge (ESD). Furthermore, systems may be required to operate in severe electromagnetic environments, such as during lightning strikes, and withstand threats such as electromagnetic pulses (EMPs). Because connectors act as a transmitting or receiving antenna, the grounding, filtering, and shielding on the connectors plays an important role in optimizing EMC. Connectors must comply with several domestic and international standards governing EMC prior to commercial release. Connector in a fully assembled configuration or in the complete terminated assembly are subjected to EMI testing. There are several techniques to help achieve EMC including grounding, shielding, balanced lines, and filtering. All have their place as well as their limitations, depending on the applications and the severity of the EMI problem. EMI and EMC testing are performed per the following standards:

IEC 61000-4-3: Electromagnetic compatibility (EMC) – Part 4-3: Testing and measurement techniques – Radiated, radio-frequency, electromagnetic field immunity test

IEC 61000-4-4: Electromagnetic compatibility (EMC) – Part 4-4: Testing and measurement techniques – Electrical fast transient/burst immunity test

IEC 61000-4-5: Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test

IEC 61000-4-6: Electromagnetic compatibility (EMC) – Part 4-6: Testing and measurement techniques – Immunity to conducted disturbances, induced by radio-frequency fields

IEC 61000-4-7: Electromagnetic compatibility (EMC) – Part 4-7: Testing and measurement techniques – General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto

IEC 61000-4-8: Electromagnetic compatibility (EMC) – Part 4-8: Testing and measurement techniques – Power frequency magnetic field immunity test

IEC 61000-4-9: Electromagnetic compatibility (EMC) – Part 4-9: Testing and measurement techniques – Pulse magnetic field immunity test

IEC 61000-4-10: Electromagnetic compatibility (EMC) – Part 4-10: Testing and measurement techniques – Damped oscillatory magnetic field immunity test

IEC 61000-4-11: Electromagnetic compatibility (EMC) – Part 4-11: Testing and measurement techniques – Voltage dips, short interruptions and voltage variations immunity test

IEC 61000-4-12: Electromagnetic compatibility (EMC) – Part 4-12: Testing and measurement techniques – Oscillatory waves immunity test

IEC 61000-4-13: Electromagnetic compatibility (EMC) – Part 4-13: Testing and measurement techniques – Harmonics and interharmonics including mains signalling at a.c. power port, low frequency immunity tests

IEC 61000-4-14: Electromagnetic compatibility (EMC) – Part 4-14: Testing and measurement techniques – Voltage fluctuation immunity test

IEC 61000-4-15: Electromagnetic compatibility (EMC) – Part 4-15: Testing and measurement techniques – Flickermeter – Functional and design specifications 1

IEC 61000-4-16: Electromagnetic compatibility (EMC – Part 4-16: Testing and measurement techniques – Test for immunity to conducted common mode disturbances in the frequency range 0 Hz to 150 kHz immunity test

10.6 Temperature Life Testing

For the temperature life test, the connector is exposed to constant elevated temperature. This temperature could be either the rated temperature of the connector or the maximum ambient temperature at which the connector is expected to work. Electrical loading can be performed during the operation of the connectors. In the case of signal connectors, electrical loading will not cause any significant increase in temperature and can be ignored. However, in the case of power connectors, electrical loading will cause a significant rise in temperature. Therefore, the test temperature should be brought down in case the connector is operating at maximum rated conditions. In the case of the ambient temperature test, the temperature of the surroundings should be brought down if the sum of the ambient temperature and temperature rise due to electrical loading goes beyond the rated temperature of the connector.

The temperature tests evaluate potential degradation mechanisms such as dry oxidation mechanisms; diffusion, migration, or intermetallic compound formation; potential creep tendencies of plastics under stress with the possible loss of contact retention and normal force; and stress relaxation of contacts, which may result in a loss of normal force and hence a loss of mechanical stability over time [5].

When the connector is to be used in ambient temperature conditions, a temperature rating of 65 °C is often used. When high-power devices are to be operated, a temperature rating of 85 °C is often used. When tin and its alloys are used in the connector, a temperature rating of 105 °C may be used. Cobalt-hardened gold connectors are tested at 125 °C. A 240-hour test is usually sufficient to establish the magnitude of stress relaxation that may occur (assuming that the trend can be determined). A 1000-hour test is required to evaluate all the potential degradation factors described earlier [6]. Per IEC 60512-11-9, the connector specimens are subjected to a 125 °C temperature for a period of 168 hours (1 week).

10.7 Temperature Cycling with Humidity Testing

Temperature cycling with humidity is a dynamic test wherein the temperature is cycled between two extremes while at high humidity. The purpose of this test is to: (i) determine the sensitivity of the housing material to swelling, moisture absorption, and dimensional stability; (ii) determine the susceptibility of the connector system to the wet oxidation process; (iii) check the susceptibility of the contacting surfaces to fretting corrosion due to the thermal cycling environment; and (iv) verify whether the wet oxidation process happens to the materials in contact as well as any wear debris or particulates that may be present on these surfaces [8].

10.8 Thermal Cycling Testing

In a thermal cycling test, the temperature is varied between two extremes with a specific ramp time. This test is the same as temperature cycling with humidity except that the humidity is absent. It evaluates the same factors as mentioned earlier with the addition of fretting degradation due to thermal excursions and the associated thermal expansion mismatches in the connector system [6].

10.9 Thermal Shock Testing

The thermal shock test is similar to the thermal cycling test except that the ramp-up and ramp-down times are extreme, because the item under test is moved from one temperature extreme to the other. Thermal shock is used to test the ability of the connector to withstand the shock of alternate exposures to extreme temperature, which could arise in some storage, transportation, and application conditions (e.g. going from an outside environment to an inside environment). This test is used to assess and explore the connector's susceptibility to fretting corrosion, features involving different materials, and significantly different masses (e.g. the effects of thermal dissipation) of the materials [6]. IEC 60068-2-14 provides the details of the test that involves rapid cycling from cold to hot. This test determines the ability of connectors to withstand rapid changes of ambient temperature. The exposure times adequate to accomplish this are selected based on the nature of the connector specimen. The connector specimen is exposed to rapid changes of temperature in air, or in a suitable inert gas, by alternate exposure to low temperature and to high temperature. Two separate chambers or one rapid temperature change rate chamber may be used. If two chambers are used, one for the low temperature and one for the high temperature, the location allows transfer of the specimen from one chamber to the other within the prescribed time. Either manual or automatic transfer methods may be used. The severity of the test is defined by the combination of the two temperatures, the transfer time, the exposure time of the specimen, and the number of cycles. The lower and higher temperatures are selected from the test temperatures of IEC 60068-2-1 and IEC 60068-2-2. The exposure time of each of the two temperatures depends upon the heat capacity of the specimen. It may be 3 hours, 2 hours, 1 hour, 30 minutes, or 10 minutes, or as specified in the relevant specification. Where no exposure period is specified in the relevant specification, it is understood to be 3 hours. The preferred number of test cycles is five, unless otherwise specified in the relevant specification. The two-fluid-bath method determines the ability of connectors to withstand rapid changes of temperature and is applicable to specimens with glass-metal seals. In this test, the specimen is immersed alternately in two baths, one filled with liquid at low temperature and one filled with liquid at a high temperature. The liquids used for the test are compatible with the materials and finishes used in the manufacture of the connector specimens. The rate of heat transfer will depend upon the liquids used and will affect the severity of the test for a given temperature range. In special cases, the relevant specification should specify the liquids to be used.

10.10 Humidity Testing

Steady-state humidity testing is performed at a constant temperature and relative humidity (RH)˙˙ [6],[4] Since this test is conducted in a static environment, its effectiveness is limited. In a situation when the test chamber humidity is cycled instead of

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[4] MIL-STD 1344, Method 1002.2: *Test Methods for Electrical Connectors: Humidity.*

being held at a constant state, the insulating materials are subjected to creep loads and the materials exhibit higher creep rates than in a constantly humid state. This higher creep is a more general phenomenon consistent with sorption-induced stress-gradient explanations.

The purpose of this test is to: (i) determine the sensitivity of the plastic material to swelling, moisture absorption, and dimensional stability; (ii) determine the susceptibility of the connector system to the wet oxidation process; and (iii) determine the potential surface degradation of a plastic housing. The two common test condition combinations used are 40 °C and 95% RH, and 85 °C and 85% RH [7].

Some standards for humidity testing are listed here for reference:

EIA-364-31F: Humidity Test Procedure for Electrical Connectors and Sockets
MIL-STD 1344, Method 1002.2: Test methods for electrical connectors: Humidity

10.11 Corrosion

At the heart of every electrical contact is the interface. For an electrical contact to adequately perform its function over a normal operating life, the contact interface must establish and maintain a low, stable contact resistance. The conductive, metallic contact area essentially determines the contact resistance over the life of the electrical contact. Due to surface roughness, contact between two surfaces is achieved only at higher isolated points where the asperities on the two mating surfaces touch. The surfaces are not in contact away from the asperities [8].

Corrosion affects contact resistance in two ways. First, corrosive attack can occur at the periphery of any or all of the contact spots, and the constriction resistance increases as the contact spot area and the spot distributions are reduced in size. Second, corrosion products can occur in the spaces between the contact spots. The corrosion occurring in this region can affect the contact resistance in three ways. First, a contact spot might occur in the proximity of a corrosion product and then the contact spot returns to its original position, resulting in a circuit intermittent. Alternatively, the contact might ride up on the corrosion product and remain there. Finally, when the contact spot moves back, it might carry the corrosion product back. In all of these cases, the end result is the same: contact resistance is increased.

Electrical connectors typically fall into one of three categories: pin-in-hole, edge and socket, and pressure connectors. Pin-in-hole connectors normally use wire ribbons and require attaching either the male or female part of the connector to the board. The pin-in-hole connection is limited by the increase in insertion force and the number of connections. Edge connections are achieved by designing a row of fingers on the rigid board. The edge of the board is inserted into a socket that has spring-loaded contact fingers. This design is seen predominately in motherboard–daughterboard interconnections. The third connection scheme involves plating rows of contact fingers on the printed wiring board and forming rows of gold bumps on a flexible printed wiring ribbon. The third connection scheme is more costly than the other two but allows for the highest density of interconnection.

Flexible printed wiring has become an increasingly attractive alternative for connecting electronic equipment. In a growing number of applications, flexible connectors have been used to replace the traditional wire ribbon connectors. One particular advantage over wire cable connectors is a higher level of interconnection and better surface contact. In addition, flexible printed wiring connectors have better control of electrical characteristics, as well as aesthetic appeal.

In all connection designs, the electrical contact resistance at the connection is a primary concern. Contact resistance is typically reported either as electrical resistance versus force or as electrical resistance versus pressure. The contact resistance is a function of the materials, geometries, and contact area. Changes in the contact resistance can be attributed to a change in contact area and materials due to wear and corrosion. Copper, which is used in most printed wiring board designs, is extremely susceptible to corrosion from chlorides and sulfides. In addition, copper oxidizes relatively quickly. Oxide films can result in up to 1000 times increase in the contact resistances. Gold surface finishes are used in high-reliability applications due to good electrical characteristics and resistance to corrosion. The contact resistance for clean gold surfaces is typically below 1 mΩ. The gold-to-gold contact resistance under minimum load conditions starts about seven to eight times lower than the gold-on-copper contact resistance. As the contact area increases with increased load, the copper-to-gold contact resistance approaches the equivalent gold-to-gold contact resistance.

In pressure contact connections, the contact load is a design parameter that must be considered as well as movement at the contact interface due to temperature expansion mismatches. Movement produces surface wear of the noble plating finish, which can expose the non-noble base material to corrosive agents. In addition, particles produced during wear can cause shorts and opens.

Previous work [9–13] on common contact metals such as aluminum, copper, and nickel have shown that surface films are one of the key factors affecting the conductive area in contact between two metallic surfaces. When electrically insulating films cover a portion of the asperities in contact, the total area of electrical contact is reduced, thus increasing the contact resistance. As the corrosion films cover the contact surfaces, many of the original metal-to-metal asperity electrical contacts have been changed into, or replaced by, insulating asperities. Several researchers [12, 14, 15] have shown that the electrical contact area is decreased with the ingress of surface films such as oxides onto the asperities.

Usually a copper alloy is used as the base metal for contact pins and springs. They are plated with precious metal to increase corrosion resistance. The gold contact plating typically will be in the range of 0.4–1.3 mm thick. However, despite having noble metal plating, corrosion is still a problem due to porosity in the plating. Porosity is a function of the plating process used, and for a given process, the porosity is directly proportional to the thickness of the noble metal plating – the thicker the plating, the lower the porosity. Porosity exposes the non-noble under plate or base metal to the environment, which leads to its corrosion. These corrosion products creep out of the pores and spread over the noble metal plating.

Testing must be conducted to assess the potential connector failure mechanisms of pore corrosion, edge creep, corrosion due to particulates or contaminants on the contact surfaces, and corrosion of non-noble material systems. The key environments that can lead to such degradation are temperature, humidity, gaseousness, and dust.

Corrosion can be categorized as four types: dry, creep, moist, and fretting. The following sections discuss these types.

10.11.1 Dry Corrosion

Dry corrosion occurs when an oxidizing gas is present. It does not require the presence of a liquid electrolyte. The copper oxides are both ionic and electronic conductors; thus, the oxide layer serves as the electrolyte. The oxide layer also forms the electrode where oxygen is reduced and forms the diffusion layer through which the ions and electrons must migrate. The more metal-rich oxides exist at the metal interface, while the more oxygen-rich oxides exist at the atmospheric interface.

A surface cross section of copper would reveal the following layers: Cu, CuO, CuO_2, and O_2. The film generated by dry corrosion on copper is porous, and is electrically insulating but not self-limiting. In addition to the noble metal plating on the contact surface, nickel underplating is often employed as a two-way barrier against corrosion. The migration of copper to the contact surface is drastically slowed down because copper diffuses through nickel approximately 1000 times slower than through gold. Nickel exposed at the base of the pores in the gold plating forms a self-limiting film that does not grow out of the pore defect and covers the gold surface [16].

10.11.2 Creep Corrosion

Corrosion products can be generated at pores and any other places (cracks, edges, scratches) where the base metal is exposed to the environment and can spread over the protective precious metal coating without reacting chemically with the plating. This phenomenon, known as “creep corrosion,” could be regarded as an extension of the pore corrosion process, especially when corrosion products from adjacent pores begin to merge with each other [17]. However, it is believed that pore corrosion is driven primarily by chlorine ions, while creep corrosion is usually a sulfur-dominant process [18]. In mixed flowing gas (MFG) testing, an established accelerating corrosion test for qualification of connectors [19], creep corrosion is regarded more as a separate failure signature than pore corrosion.

Sulfide products, especially silver sulfide, creep at the highest rate [20]; other reacting products, such as chloride, do creep but at orders of magnitude lower than those of sulfides. Creep of all products is highest across pure gold. A study on creep corrosion phenomena of IC packages [21] found that creep corrosion may also occur on a plastic surface. In this case, creep corrosion products were found to be a mixture of chloride and sulfide of the base metal (copper) and the diffusion-barrier plating layer (nickel).

The physics behind the phenomenon of corrosion products creep is not yet apparent. However, two theories are being considered. The first, a surface diffusion theory, states that creep corrosion is driven by concentration gradients of chemical species of the corrosion product [22]. A surface diffusion coefficient can be used to quantify the mobility of corrosion products over a surface under given environmental conditions. The second, a galvanic corrosion theory, provides another interpretation [23]. Metallic ions move from anode (base metal) toward cathode (noble plating) and are deposited near the cathode, combining with other anions in the electrolyte. In this way, corrosion products propagate over a noble metal plating surface and have a tendency to cover more area of the plating surface.

The effect of creep corrosion on contacts is the degradation of performance by increasing the contact resistance. Once corrosion products begin to spread over a plating surface, the contact resistance of the surface increases, owing to the poor electrical conductivity of corrosion products. Noise in the electrical signals or current leakage may occur [18].

In engineering design of contacts with noble metal plating, the resistance to creep corrosion is usually considered as a critical characteristic. MFG tests are often conducted in the laboratory to reproduce creep corrosion phenomena to simulate field use, and contact resistance can be measured to evaluate the effect of creep corrosion [18].

10.11.3 Moist Corrosion

Moist corrosion is caused by the humidity in the air. A thin layer of moisture from the ambient RH combines with gaseous corrosion drivers to form an electrolyte. Either a galvanic cell or a differential cell is created with the metals of the electrical contact forming the anode and cathode, while monolayers of water contaminated with such impurities as chlorine and sulfur form the electrolyte [17].

A contact may be susceptible to creep corrosion if the intended contact area has been selectively gold-plated. This phenomenon occurs when sulfides cause tarnish films to form on exposed copper and migrate across the gold-plated surfaces, electrically insulating them. In addition, pores on the gold plating surface (called "pores") are a source of the creep corrosion. Copper exposed at the base of the pores in the gold plating forms the corrosion products that grow out of the pore and creep over the gold surface. An electrical contact surface affected by pore corrosion develops discrete "mounds" of corrosion on an otherwise uncorroded (native) surface. Discontinuities in the plated surface and a corrosive environment are required for pore corrosion to occur [17].

Pore corrosion can also cause a mechanical disruption in the plating. The corrosive products formed at the base of the pore have a larger volume because they are less dense than base copper. As the new corrosive products form, they can exert a force on the plating layers to break them apart. This disruption exposes more of the corrosion-prone underplate and intensifies the corrosion problem [17].

It is not always possible to differentiate between these two types of atmospheric corrosion because, depending on the corrosion conditions, there may be a gradual transition from one form to another. Structures initially corroded in air by the dry corrosion mechanism can begin to corrode by the moist mechanism as a result of increase in moisture or formation of hygroscopic corrosion products [17].

10.11.4 Fretting Corrosion

Owing to the increasing number of low-power connections in electronic packaging, fretting corrosion of electrical contacts is becoming more of a concern. Thermal cycling, as well as ordinary micro-vibration, provides the driving mechanism for the micromotion that induces fretting corrosion, thereby decreasing the reliability of the electrical system [17].

Fretting occurs when two contacts are brought together with a given contact normal force and then moved with respect to each other cyclically. This motion is typically 10–100 μm in amplitude at a frequency dependent on the driving mechanism. The degree of fretting corrosion is highly dependent on environmental conditions, frequency, normal force, contact materials, and presence of lubricants. However, the increased resistance associated with fretting corrosion is only one part of the problem. Electrical intermittences associated with the fretting process can degrade digital circuit signals [17].

Gold-plating technology has been widely used to decrease fretting corrosion in electrical contacts. However, formation of an insulating surface film and further fretting corrosion in the gold-plated contacts as a result of the gold-plate damage and diffusion of substrate metal through gold is still one of the major concerns in producing reliable electrical contacts with low contact force application [17].

10.12 Mixed Flowing Gas Testing

One of the most widely used environment tests is the MFG test. This test is considered to be a realistic accelerated test that is designed to simulate the kinetics and degradation mechanisms found in indoor environments. Battelle Laboratories in Columbus, Ohio, conducted a study on electrical contacts and developed four classes, each associated with a distinct pollutant. It found that while the environment class depends on the pollutants in the environment, it is best defined by how the degradation of the contact materials occurs.

There are four environment classes. Class I represents a benign, nonindustrial business office environment with good atmospheric control. Class II represents typical conditions in business offices, control rooms, and telephone exchanges that are associated with a light industrial area. Class III represents poorly controlled industrial and related locations where moderate amounts of pollutants are present. Class IV represents extremely corrosive, highly polluted, and heavily industrial locations. Table 10.3 outlines the predominant degradation mechanism and the pollutants that are present in the various environment classes.

Tests may be conducted on plated metallic coupons rather than on actual connector samples if the similarity is appropriate. The coupons are placed in the accelerated chambers for varying periods of time. They are then taken out, and their contact resistance is measured using a contact resistance probe. The probe measures contact resistance at varied normal forces.

An MFG test is a laboratory test in which the temperature, relative humidity, concentration of gaseous pollutants, and other critical variables (such as volume exchange rate and airflow rate) are defined, monitored, and controlled. The purpose of this test is to simulate corrosion phenomenon due to atmospheric exposure [20]. Test samples that have been exposed to MFG testing range from bare metal surfaces to electrical

Table 10.3 Predominant degradation mechanism and pollutants in the environment classes.

Class	Degradation Mechanism	Pollutants
I	Pore corrosion	Humidity, low chlorides
II	Surface and pore corrosion	Chlorides
III	Pore corrosion and edge corrosion creep	Chlorides, sulfides
IV	Edge corrosion creep – chloride-enhanced or sulfide-dominant	Chlorides, sulfides

connectors to complete assemblies. MFG testing has been widely accepted as a qualification test method to evaluate the performance of connectors.

In the 1980s, researchers at Battelle Labs (Columbus, OH), Telcordia (previously Bellcore), and IBM carried out tests on the use of MFG to accelerate atmospheric corrosion and its effect on electronic applications. In the early 1990s, professional organizations, including the ASTM, EIA, IEC), and Telcordia, began to standardize these test methods and published corresponding documents as guidelines. Among them, ASTM provided a comprehensive list of documents covering the methods for a well-controlled MFG test. These documents include the following:

ASTM B827-97: Standard practice for conducting mixed flowing gas environmental tests
ASTM B845-97: Standard guide for mixed flowing gas tests for electrical contacts
ASTM B810-01a: Standard method for calibration of atmospheric corrosion test chambers by change in mass of copper coupons
ASTM B825-97: Standard test method for coulometric reduction of surface films on metallic test samples
ASTM B826-97: Standard test method for monitoring corrosion tests by electrical resistance probes
ASTM B808-97: Standard test method for monitoring of atmospheric corrosion chambers by quartz crystal microbalances

ASTM International, which grows from US industry, is a nonprofit organization that provides a global forum for the development and publication of voluntary consensus standards for materials, products, systems, and services.[5] ASTM publishes voluntary consensus standards for materials, products, systems, and services. Therefore, ASTM standards are more likely a review of existing MFG practices, rather than a mandatory procedure for individual situations. The EIA is a US national trade organization that includes the full spectrum of US electronic product manufacturers.[6] The IEC, primarily based on the European electronics industry, is the international standards and conformity assessment body for all electrical, electronic, and related technologies.[7] For industrial applications, the following test methods are more specific and application-oriented. Each MFG test method is reviewed in the following sections.

IEC 68-2-60 (second edition): Environmental testing – Part 2: Tests – Flowing mixed gas corrosion test
EIA 364-TP-65A: Mixed flowing gas
Telcordia GR-63-CORE Issue 2, Section 5.5: Airborne contaminants test methods

Each MFG test method is reviewed next.

10.12.1 Battelle Labs MFG Test Methods

Table 10.4 lists the classifications and parameters for the Battelle Labs MFG test methods. The operational environments for electronic equipment in atmosphere are divided into four classes, from least corrosive (Class I) to most corrosive (Class IV).

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[5] American Society for Testing and Materials (ASTM): www.astm.org
[6] Electronic Industries Alliance (EIA): www.eia.org
[7] International Electrotechnical Commission (IEC): www.iec.ch

Table 10.4 MFG test methods developed by Battelle Labs [15].

Class	Temp (°C)	RH (%)	H_2S (ppb)	Cl_2 (ppb)	NO_2 (ppb)
I	—	—	—	—	—
II	30 ± 2	70 ± 2	$10 + 0/-4$	$10 + 0/-2$	200 ± 25
III	30 ± 2	75 ± 2	100 ± 10	20 ± 5	200 ± 25
IV	50 ± 2	75 ± 2	200 ± 10	50 ± 5	200 ± 25

Class I means a well-controlled office environment with continuous adjustment. Class II means a light industrial environment, such as business offices without effective or continuous environment control. Class III means a moderate industrial environment, such as storage areas with poor environment control. Class IV means a heavy industrial environment, such as locations adjacent to primary sources of atmospheric pollutant gases. Since available data for Class I indicates no precedent for environmental effects on reliability, there is no accelerated testing for Class I. The other three classes use a combination of three corrosive gases, NO_2, H_2S, and Cl_2, to accelerate corrosion. Most other standards also use a fourth gas, SO_2. The reason is that some researchers believe that H_2S and SO_2 have the same synergistic effects on metal corrosion and SO_2 is necessary to stress nickel in corrosive environments [24].

Since an MFG environment is an accelerated testing method, the determination of acceleration factor is required to understand the durability or reliability of the "device-under-test." In other words, if a sample has a certain degree of corrosion after *N* days in the testing chamber, how long would it take to have the same amount of corrosion in the fielded conditions? However, there is currently no model for this, although some authors suggest an acceleration factor of two days in the chamber for one year in the field for Battelle accelerated test conditions [25].

10.12.2 EIA MFG Test Methods: EIA 364-TP65A

EIA published its own specifications for MFG testing, as shown in Table 10.5. The latest version was approved on November 6, 1997. Class II, III, and IV parameters come directly from Battelle research. Classes IIA and IIIA are adapted from Classes II and III by adding SO_2 along with the other three corrosive gases.

Table 10.5 MFG test methods developed by EIA.

Class	Temp (°C)	RH (%)	H_2S (ppb)	Cl_2 (ppb)	NO_2 (ppb)	SO_2 (ppb)
I	—	—	—	—	—	—
II	30 ± 2	70 ± 2	10 ± 5	10 ± 3	200 ± 50	—
IIA	30 ± 1	70 ± 2	10 ± 5	10 ± 3	200 ± 50	100 ± 20
III	30 ± 2	75 ± 2	100 ± 20	20 ± 5	200 ± 50	—
IIIA	30 ± 1	70 ± 2	100 ± 20	20 ± 5	200 ± 50	200 ± 50
IV	40 ± 2	75 ± 2	200 ± 20	30 ± 5	200 ± 50	—

Table 10.6 MFG test methods developed by IEC.

Method	Temp (°C)	RH (%)	H_2S (ppb)	Cl_2 (ppb)	NO_2 (ppb)	SO_2 (ppb)
1	25 ± 1	75 ± 3	100 ± 20	—	—	500 ± 100
2	30 ± 1	70 ± 3	10 ± 5	10 ± 5	200 ± 50	—
3	30 ± 1	75 ± 3	100 ± 20	20 ± 5	200 ± 50	—
4	25 ± 1	75 ± 3	10 ± 5	10 ± 5	200 ± 20	200 ± 20

10.12.3 IEC MFG Test Methods: IEC 68-2-60 Part 2

IEC 68-2-60 Part 2 about MFG testing was published in December 1995 but is now withdrawn. Table 10.6 shows the parameters for MFG testing by IEC 68-2-60. Test method 1 can be used as a pore corrosion test on gold coatings. Test method 1 is for testing of contacts with gold-plated surfaces to be used in mild environments. Test methods 2 and 4 are appropriate for electronic products to be used in moderate corrosive environments. Such environments may be found in telecommunication centers, most office environments, and some industrial instrument rooms. Test method 3 is appropriate for more corrosive environments. Such environments may be found in some industrial locations.

10.12.4 Telcordia MFG Test Methods: Telcordia GR-63-CORE Section 5.5

Telcordia, previously known as Bellcore, is a center that provides standardization within the telecommunication industry. MFG test methods developed by Telcordia focus on electronic equipment in telecommunication applications. Since these kinds of equipment may operate indoors or outdoors, two MFG test methods are available from Telcordia, which are known as indoor and outdoor tests. Table 10.7 lists the parameters for these two methods.

10.12.5 IBM MFG Test Methods: G1(T)

In contrast to Battelle and Telcordia, IBM divided the working conditions for electrical equipment into three classes, which are G1 (business office), G2 (industrial), and G3 (harsh industrial). To simulate the accelerated corrosive effect of equipment in the G1 environment, IBM designed and verified the G1 (T) MFG test environment, where it used four corrosive gases. IBM's recommended gas concentrations are very different from that of Battelle (see Table 10.8) [26]. Interestingly, the IBM MFG test method has not gained much popularity in the industry, perhaps because of the costs of using four gases.

Table 10.7 MFG test methods developed by Telcordia.

Method	Temp (°C)	RH (%)	H_2S (ppb)	Cl_2 (ppb)	NO_2 (ppb)	SO_2 (ppb)
Indoor	30 ± 1	70 ± 2	10 ± 1.5	10 ± 1.5	200 ± 30	100 ± 15
Outdoor	30 ± 1	70 ± 2	100 ± 15	20 ± 3	200 ± 30	200 ± 30

Table 10.8 G1 (T) MFG test method developed by IBM.

Temp (°C)	RH (%)	H_2S (ppb)	Cl_2 (ppb)	NO_2 (ppb)	SO_2 (ppb)
30 ± 0.5	70 ± 2	40 ± 5%	3 ± 15%	610 ± 5%	350 ± 5%

Figure 10.3 MFG chamber located at CALCE at the University of Maryland.

Table 10.9 CALCE MFG chamber capability.

		Corrosive Gas Concentrations (ppb)				
Temp. Range (°C)	RH (%)	NO_x	SO_2	H_2S	Cl_2	Interior Dimensions (inches)
25 ~ 50	20 ~ 95	10 ~ 1000	10 ~ 1000	10 ~ 1000	10 ~ 1000	29 × 30 × 38

10.12.6 CALCE MFG Chamber Capability

The Center for Advanced Life Cycle Engineering (CALCE) at the University of Maryland provides quality services to electronic applications that require testing using an MFG chamber. Figure 10.3 shows this MFG testing system. Table 10.9 lists the capability of the MFG chamber, including up to four corrosive-gas-testing.

Mechanisms of electrical connector failures include film growth that influences contact force and voltage drop. Contact force can suppress surface film growth either through a pore in a gold layer or ingress at the contact area, which contributes to the resistance stability of electrical contacts [17].

10.13 Vibration

The purpose of the vibration test is to establish the mechanical integrity of the connector as part of a product or system. The test can be used to determine whether the electrical system is stable under vibration conditions, to determine discontinuities that may exist in the electrical system, and to check the susceptibility of the connector(s) in the system to fretting wear and corrosion. Too often, vibration is included in connector testing without any real thought as to what purpose the vibration serves. Mechanical vibration is typically used as a test environment to establish or verify the mechanical integrity of connector, to determine whether electrical discontinuities exist, the impact on electrical stability, and to determine whether the connector system is susceptible to fretting wear or corrosion. Typical vibration testing is either monitored or unmonitored. The monitored testing typically is looking for interruptions in contact resistance of 1 μs or longer. More recent test requirements for high-speed systems are looking at interruptions of 10 Ω or more in a time frame of 10 ns (known as low nanosecond events). Unmonitored vibration testing relies upon low-level contact resistance (LLCR) measurements to detect the presence of contact degradation.

It is recognized that test sequencing must be considered; i.e. a monitored vibration test cannot proceed with an LLCR measurement due to current-induced oxide breakdown, but traditional vibration testing does not fully consider the role of vibration in precipitating and detecting potential connector failures. The connector failure mechanisms that are driven by vibration include acceleration-driven contact separation, contact wear, and contact fretting.

The vibration test is typically performed on the three axes of the system under test. The most common types of vibration tests are sine vibration, random vibration, and vibration scans. Sine vibration tests involve sweeping through various frequencies at a defined amplitude and seep duration. In the random vibration test, the frequencies and amplitude appear randomly in a given frequency spectrum. The vibration scan test is performed to identify the dominant resonances in the connector. Then the connector can be vibrated at the dominant resonant frequencies for a specified period of time.

The effects of vibration on connector performance can be monitored by measuring interruptions in resistance and the variation in the LLCR.

Some standards for vibration testing are listed here for reference:

EIA 364-28C: Vibration test procedure for electrical connectors and sockets
IEC 60512-6-5: Dynamic stress test – section 5: test 6a: random vibration
MIL-STD 1344, Method 2005.1: Test methods for electrical connectors: vibration

10.13.1 Mechanical Shock

The mechanical shock test is meant to simulate conditions a connector may be subjected to during assembly, transportation, and other forms of handling. The mechanical shocks should be associated with the range of conditions expected and often vary from 30 to 300 G with specified durations. When this test is used to simulate transportation conditions, it is often performed as a precursor to vibration tests.

10.13.2 Mating Durability

Mating durability is a test to simulate the wear of a connector finish system normally expected during the anticipated life of the connector. The test is normally performed using automatic cycling equipment with an adjustable speed control and counter system. The rate of cycling has to be controlled to prevent frictional heating.

Two basic attributes need to be monitored during this test: mating/unmating forces on the first and last cycles and LLCR and contact resistance at rated current (CRRC) upon completion of the test. These attributes will determine whether the force requirements are met and the electrical stability and mechanical integrity are maintained.

10.14 Highly Accelerated Life Testing

Highly accelerated life testing (HALT) can uncover many of the weak links of a new product. These accelerated tests are used for finding weaknesses at various steps of a manufacturing process. Design weaknesses are easier to correct during product development, resulting in reduced product development costs and compressed time-to-market. When accelerated tests are used after the products are introduced into the market, they can determine product reliability due to changes in components, suppliers, and manufacturing processes. Because of their accelerated nature, these tests are typically faster and less expensive compared to normal tests [27].

In highly accelerated life tests, environmental stresses are applied to the system. These stresses eventually lead to product failure when the stress applied becomes more than that expected during use. The stresses applied are typically cold and hot temperatures, thermal cycling, power cycling, random vibrations, and power margining. When stress-introduced failures occur, the causes for the failure should be identified and corrected. The tests are then repeated, the second test can also identify additional weaknesses, in addition to verifying the effectiveness of the correction.

The typical HALT chamber should be capable of applying a pseudo-random vibration with frequency ranging to 10 000 Hz in 6° of freedom, with the ability for rapid changes in temperature. Often, high-power resistive heating elements are used for heating and liquid nitrogen (LN_2) for cooling purposes [28].

The product under test must be monitored continuously to detect degradation and failure. The test equipment usually includes thermocouples, performance measuring sensors, accelerometers, data loggers, and multimeters. The most common causes of failure in these tests are weak product design, bad workmanship, and poor manufacturing techniques [28].

10.15 Environmental Stress Screening

Environmental stress screening (ESS) refers to the process of exposing a newly manufactured or repaired product or component to stresses such as thermal cycling and vibration to force the latent defects to manifest themselves by permanent or catastrophic failures. The remaining population is assumed to be more reliable than a similar unscreened population.

ESS tests are mainly used for military and aerospace applications. The tests usually involve temperature variations, vibration tests, and pressure and flexibility tests. ESS can be performed as part of the manufacturing process, or it can be used in new product qualification testing.

The various steps involved in manufacturing processes are as follows: Visual inspection is done first. Testing of the product is done to check whether the unit under test

(UUT) is within design guidelines. Then the physical environment conditions that the product will face in its lifetime, including during the transportation, storage, handling, and operational use phases, are simulated and applied. This includes vibration tests while transporting the product and thermal cycling tests while using it. Qualification is done to ensure that the design, manufacturing, assembly, and repair processes have resulted in a product that conforms to the specifications. Typically, qualification samples are derived from several production lots to ensure that the assessment covers the extent of the variability of the process. The qualification procedures used are: MIL-STD 810H for line replaceable unit (LRUs), MIL-STD 202G for electronic piece parts, and MIL-STD 883H for microelectronic devices. EMI/RFI testing is usually included in ESS qualification testing and requires application of MIL-STD 461E. The qualification tests generally involve aggravated ESS testing, which means subjecting a UUT to harsher conditions than it will experience in its lifetime. These are destructive tests. There is then acceptance ESS where the products are tested to specifications given by the procurement agency. Passing this test means the unit is accepted by the procurement agency.

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